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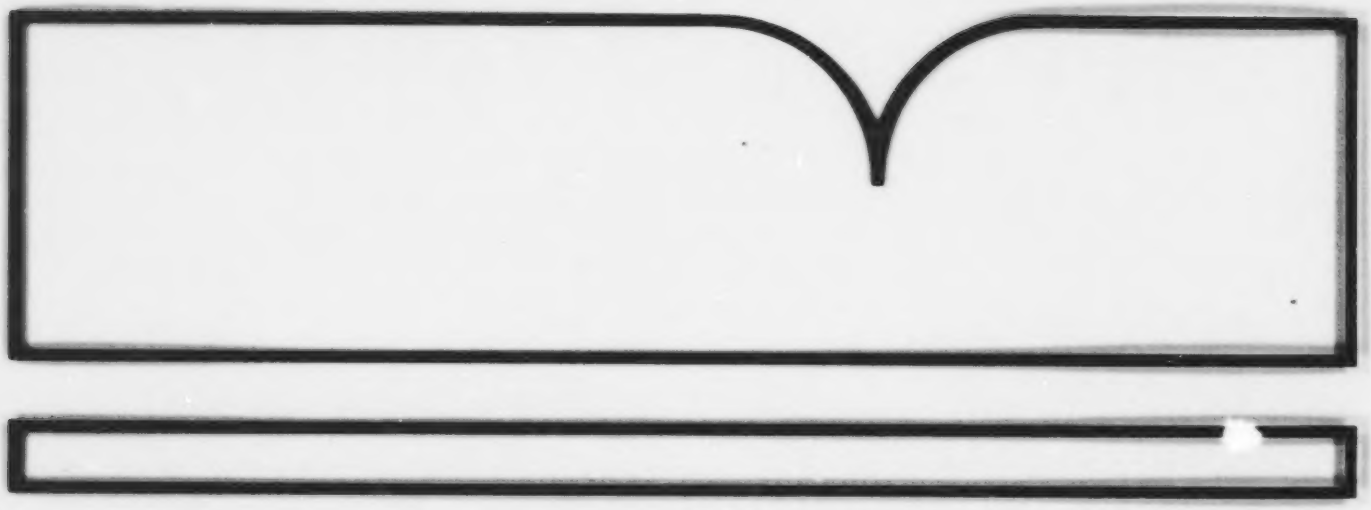

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THE DEVELOPMENT OF SULFUR DIOXIDE AND OZONE EXPOSURE PROFILES THAT MIMIC AMBIENT CONDITIONS IN THE RURAL SOUTHEASTERN UNITED STATES

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Abstract—A design for constructing experimental mixed-pollutant exposure profiles that reflect regional O_3 and SO_2 ambient air quality is described. The profiles were developed using hour-by-hour O_3 and SO_2 concentration data from monitoring sites in the southeastern United States where slash pine is indigenous. Only sites designated rural or remote, with co-monitored O_3 and SO_2, and at least 75% of the hourly values reported for the period April–October, were used. Each site was characterized by concentration, frequency of occurrence and duration of concentration values, length of time between episodes, and frequency of co-occurrence. A base profile, a 30-day hour-by-hour concentration regime, was constructed using averaged air quality characteristics from the selected sites. Using the base profile, additional regimes were constructed by increasing the concentration of all hourly values above a designated minimum, or by increasing the frequency of occurrence of selected hourly concentrations.

Key word index: Air quality, altered concentration profile, ambient, co-occurrence, distribution patterns, episodes, exposure regimes, frequency of occurrence, increased frequency profile, mean duration, mixed-pollutant profiles, ozone, peak concentrations, percentile distribution, sequential co-occurrence, simulated exposure profiles, sulfur dioxide, time between episodes.

INTRODUCTION

Air pollution effects studies seldom use exposure regimes statistically similar to the real world. This has been the case for both single and mixed gaseous pollutant studies. Recently, single pollutant regimes constructed to reflect ambient air quality were reported and utilized in field exposure studies (Lefohn *et al.*, 1986; Hogsett *et al.*, 1985). Mixed-pollutant fumigation studies have the additional need to consider the frequency and duration of co-occurrence of the pollutants. For many years, researchers have limited their work to exposure regimes where both pollutants are present for several hours a day over an extended period (e.g. Tingey *et al.*, 1971; Oshima, 1978; Heggestad and Bennett, 1981; Foster *et al.*, 1983; Heagle *et al.*, 1983; Thompson *et al.*, 1984). However, recent examination of several air quality databases showed that the simultaneous occurrence of pollutant pairs (O_3/SO_2, SO_2/NO_2 or O_3/NO_2) is of a relatively short duration (a few hours), and that there is a relatively long interval (several weeks) between co-occurrence episodes (Lefohn and Tingey, 1984), indicating the need to include the temporal nature of co-occurrence in any mixed-pollutant exposure study.

This paper presents a method of constructing realistic 30-day mixed-pollutant exposure profiles using the hour-by-hour data from available air quality databases. A planned study on the effects of O_3 and SO_2 on *Pinus elliotti* (slash pine) provided the opportunity to test the approach. An exposure regime was constructed to reflect ambient air quality of the SE region of the United States where slash pine is indigenous. Hour-by-hour concentrations of O_3 and SO_2 for 30 days were assembled to reflect the average air quality characteristics of the selected monitoring sites; data on magnitude of concentration, frequency of occurrence, time between episodes, and the frequency of co-occurrence were incorporated.

METHODS AND RESULTS

The first step in constructing the base profile was selection of the monitoring sites for analysis of the air quality. For each selected site, the mean hourly O_3 and SO_2 was characterized by concentration, frequency of occurrence, duration and time of day of peak value, time interval between episodes, and frequency of O_3 and SO_2 co-occurrence. In addition to frequency, the type of co-occurrence was characterized by the number of simultaneous (i.e. same day and same time of day) and sequential (i.e. same day but not same time of day) occurrences. Finally, a 30-day hour-by-hour concen-

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tration regime of O_3 and SO_2 (base profile) was constructed from these data, averaged over the April–October period from all selected sites.

The monitoring sites were identified from the annual summary of the EPA–SAROAD air quality data base (U.S. EPA, 1979–1983). The following selection criteria were used: (1) designated rural or remote in those states where slash pine is indigenous (Alabama, Mississippi, Florida, Georgia, South Carolina); (2) simultaneous monitoring of SO_2 and O_3 during the April–October growing season; and (3) at least 50% of the hourly values reported for the calendar year. Only 10 of the 34 rural or remote sites had simultaneous monitoring of O_3 and SO_2. Three additional sites were eliminated for lack of data. The seven sites shown in Table 1 met all criteria during the years indicated. The hourly monitoring data for April–October for each year and site were screened to identify any unusual characteristics, and to ensure that at least 75% of the hourly values were reported for each month (April–October) so that the exposure characteristics of 1 month would not be weighted unrealistically. For SO_2, the Mobile, Alabama site was removed from further consideration because the maximum hourly SO_2 concentration was 0.822 ppm, more than twice the maximum recorded for the second highest site (Pensacola, Florida). Dade County, Florida and Prattville, Alabama were eliminated because there were insufficient data reported during the April–October period. Selection of the data year for the five remaining sites was partly subjective, but dependent on availability of sufficient hourly data for both O_3 and SO_2. The sites and years identified for O_3 air quality characterization were Mobile Co., Alabama, 1978; Hillsborough Co., Florida, 1978; St. Petersburg, Florida, 1979; Pensacola, Florida, 1981; and Tarpon Springs, Florida, 1981 (Table 1). The characterization of SO_2 air quality did not include the Mobile County site.

These selected sites, though all but one are from Florida, are still representative of the SE U.S. air quality, at least as evidenced by similarities in hourly average concentration percentile distributions of other monitoring sites from the region (Tables 2 and 3). The average of each percentile from the selected sites was within one standard deviation of the average from all the other sites.

Table 1. Seven sites selected from the EPA–SAROAD Annual Summaries

Site name	Year
Mobile Co., Alabama	1978,* 1981
Hillsborough Co., Florida	1978*
Pensacola, Florida	1978, 1980, 1981,* 1982
St. Petersburg, Florida	1979,* 1982
Prattville, Alabama	1981
Tarpon Springs, Florida	1981,* 1982
Dade Co. (Everglades), Florida	1982

* Sites and year selected for air quality analysis.

Each site was designated rural or remote, had co-monitored O_3 and SO_2, and had at least 50% of the hourly values reported for the year indicated.

The following parameters were calculated for each selected site over the 7-month period (April–October): (a) percentile distribution of hourly averaged concentrations for O_3 and SO_2; (b) number of hourly occurrences of O_3 and SO_2 equal to or greater than specific concentration ranges; (c) number of hours between episodes (i.e. the time between defined minimum concentrations); (d) the identification of the range of hours when the daily maximum concentrations occurred; (e) probability of sequential co-occurrence (O_3 and SO_2 peaks on the same day but not at the same time at concentrations equal to or greater than 0.05 ppm); and (f) probability of simultaneous co-occurrence (O_3 and SO_2 peaks on the same day and at the same time). These parameters were averaged over all sites and all months for the 7-month period, and the average value for 1 month was used to assemble the 30-day base exposure profile.

The percentile distribution of concentration over the 7-month period is given in Table 4 for each site, as well as the average for all sites. The frequency of occurrence of concentrations within specific ranges over 30 days for each site is given in Table 5. The average number of hourly occurrences over 30 days was derived from the 7-months' data at each site. The low standard deviations of the means indicated that the sites were relatively uniform in terms of concentration distributions at least for the years studied.

The duration of an O_3 episode was defined by establishing the time a specified minimum concentration (e.g. 0.05 ppm) was equalled or exceeded and then calculating the average number of hours or duration of this concentration or greater endured over the 7-month period (Table 6). Assuming that the minimum concentration was equalled or exceeded every day, the average 0.05 ppm O_3 episode duration, for example, was 5.2 ± 0.6 h per day.

The time of day when the peak hourly ozone occurred was determined from plots of the mean hourly concentration over the 7 months for all sites (Fig. 1). These average diurnal plots indicated that the daily maximum O_3 concentration occurred around 1400 h (Fig. 1A). A similar analysis for SO_2 identified 0900–1300 as the period of maximum SO_2 concentration (Fig. 1B).

The time between episodes was averaged for each site and over all sites (Table 7). The period was defined as beginning when the O_3 and SO_2 fell below a specified minimum concentration (e.g. 0.09 ppm) and concluding when the pollutant levels returned to that same concentration value. The average time period between 0.05 ppm episodes is 26 ± 5 h. As the minimum concentrations are increased, the time period between episodes increases to 223 and 320 h for minimum concentrations of 0.09 and 0.10 ppm, respectively (Table 7). The time between SO_2 episodes was not incorporated into the profile because there

Table 2. Ozone percentile distribution (concentration in ppm) for April–October at several sites in the SE United States

Site	Year	Percentile								
		Min. Obs.	10	30	50	70	90	95	99	Max. Obs.
Jefferson Co., AL	1981	0.000	0.000	0.008	0.032	0.054	0.077	0.089	0.112	0.166
Jefferson Co., AL	1982	0.000	0.001	0.009	0.030	0.049	0.071	0.081	0.099	0.126
* Mobile Co., AL	1978	0.000	0.000	0.007	0.022	0.040	0.060	0.070	0.087	0.120
Tuscaloosa, AL	1981	0.000	0.005	0.015	0.025	0.040	0.055	0.065	0.075	0.115
Tuscaloosa, AL	1982	0.000	0.000	0.010	0.025	0.040	0.060	0.070	0.082	0.099
Little Rock, AR	1979	0.000	0.001	0.012	0.025	0.039	0.063	0.077	0.099	0.141
Little Rock, AR	1980	0.000	0.004	0.018	0.030	0.044	0.064	0.074	0.086	0.108
North Little Rock, AR	1981	0.000	0.015	0.025	0.035	0.045	0.060	0.070	0.080	0.110
North Little Rock, AR	1982	0.000	0.014	0.025	0.035	0.043	0.057	0.063	0.075	0.119
* Hillsborough Co., FL	1978	0.000	0.008	0.015	0.025	0.035	0.052	0.062	0.092	0.138
Pensacola, FL	1980	0.000	0.003	0.018	0.029	0.043	0.063	0.072	0.089	0.136
* Pensacola, FL	1981	0.000	0.001	0.015	0.027	0.040	0.056	0.064	0.079	0.112
* St. Petersburgh, FL	1979	0.000	0.005	0.015	0.025	0.040	0.060	0.070	0.090	0.120
Seminole Co., FL	1971	0.000	0.000	0.010	0.025	0.040	0.060	0.065	0.075	0.090
Tarpon Springs, FL	1980	0.000	0.005	0.015	0.025	0.040	0.060	0.070	0.090	0.135
* Tarpon Springs, FL	1981	0.000	0.005	0.015	0.030	0.040	0.060	0.070	0.090	0.115
Paulding Co., GA	1979	0.005	0.005	0.020	0.030	0.040	0.065	0.075	0.095	0.150
Rockdale Co., GA	1981	0.005	0.005	0.005	0.025	0.040	0.070	0.085	0.110	0.155
Rockdale Co., GA	1982	0.005	0.005	0.005	0.020	0.035	0.060	0.075	0.095	0.165
Kisatchie NF, LA	1979	0.000	0.005	0.015	0.025	0.035	0.050	0.055	0.065	0.100
Kisatchie NF, LA	1980	0.000	0.010	0.020	0.030	0.040	0.060	0.065	0.080	0.105
Chester Co., SC.	1981	0.000	0.017	0.029	0.039	0.052	0.069	0.076	0.092	0.125
Chester Co., SC.	1982	0.000	0.013	0.025	0.036	0.048	0.066	0.076	0.093	0.125
Edgefield Co., SC	1981	0.000	0.013	0.023	0.033	0.043	0.062	0.070	0.084	0.096
Edgefield Co., SC	1982	0.000	0.013	0.024	0.034	0.044	0.063	0.070	0.082	0.101
Greenville Co., SC	1981	0.000	0.006	0.022	0.034	0.047	0.067	0.075	0.091	0.112
Greenville Co., SC	1982	0.000	0.000	0.016	0.028	0.041	0.064	0.072	0.088	0.116
Average of all sites		0.001	0.006	0.016	0.029	0.042	0.061	0.070	0.086	0.120
(S. D.)		0.002	0.005	0.006	0.005	0.005	0.006	0.008	0.011	0.020
Average of sites used to construct profile (*)		0.000	0.004	0.015	0.026	0.039	0.058	0.067	0.088	0.121
(S. D.)		0.000	0.003	0.004	0.003	0.002	0.004	0.004	0.005	0.010
Average of all sites except Florida		0.001	0.007	0.017	0.029	0.042	0.062	0.071	0.087	0.120
(S. D.)		0.002	0.006	0.007	0.005	0.007	0.007	0.001	0.012	0.023

The sites are either designated rural or remote in SAROAD database, or they are located within 60 miles of a National Forest and listed regardless of site designation.

(*) = Monitoring site used to construct the base profile.

Table 5. Number of hourly occurrences within specific concentration ranges over a 30-day period (720 h) for the sites used for constructing the base ozone and sulfur dioxide profiles

Pollutant	Site	Year	ppm							
			<0.03	0.03–0.049	0.05–0.069	0.07–0.079	0.08–0.089	0.09–0.099	0.10–0.119	>0.12
Ozone	Mobile Co., AL	1978	415	163	104	18	13	4	2	<1
	Hillsborough Co., FL	1978	423	195	73	11	7	6	4	<1
	St. Petersburg, FL	1979	372	204	101	23	10	7	2	<1
	Pensacola, FL	1981	333	210	104	13	4	1	1	0
	Tarpon Springs, FL	1981	354	209	119	22	9	5	2	0
	Average		390	196	100	17	9	5	2	1
	Standard deviation		29	19	17	5	3	2	2	—
	Base profile		466	143	82	15	7	4	2	1

Pollutant	Site	Year	ppm								
			<0.015	0.015–0.029	0.030–0.049	0.050–0.069	0.070–0.079	0.080–0.089	0.090–0.099	0.100–0.119	>0.12
Sulfur dioxide	Hillsborough Co., FL	1978	687	19	8	2	<1	<1	0	<1	<1
	St. Petersburg, FL	1979	644	51	14	5	1	<1	<1	1	2
	Pensacola, FL	1981	668	24	12	5	1	1	1	2	6
	Tarpon Springs, FL	1981	662	37	12	4	1	<1	1	<1	<1
	Average		665	33	12	4	1	1	1	1	2
	Standard deviation		18	14	3	1	—	—	—	—	2
	Base profile		672	21	16	3	2	2	1	1	2

Table 6. The average duration (h) of specified hourly averaged O_3 concentrations*

	Minimum hourly concentration (ppm)				
	0.05	0.07	0.08	0.09	0.10
Average of five sites†	5.2	3.7	2.9	2.4	1.9
Standard deviation	0.61	0.72	0.71	0.52	0.41
Base profile	4.3	2.9	2.3	1.8	1.0

* Defined as the length of time beginning when the concentration equals and goes above a specified concentration and ending when it returns to that same minimum value over the period April–October.

† Mobile Co., AL, 1978; Hillsborough Co., FL, 1978; St. Petersburg, FL, 1979; Pensacola, FL, 1981; Tarpon Springs, FL, 1981.

Table 7. The average number of hours betweeen specified hourly averaged O_3 concentrations*

	Minimum hourly concentration (ppm)				
	0.05	0.07	0.08	0.09	0.10
Average of five sites†	26	81	121	223	320
Standard deviation	5	9	32	81	144
Base profile	23	57	100	160	228

* Defined as the length of time beginning when the concentration falls below a specified concentration and ending when it returns to that same minimum value over the period April–October.

† Mobile Co., AL, 1978; Hillsborough Co., FL, 1978; St. Petersburg, FL, 1979; Pensacola, FL, 1981; Tarpon Springs, FL, 1981.

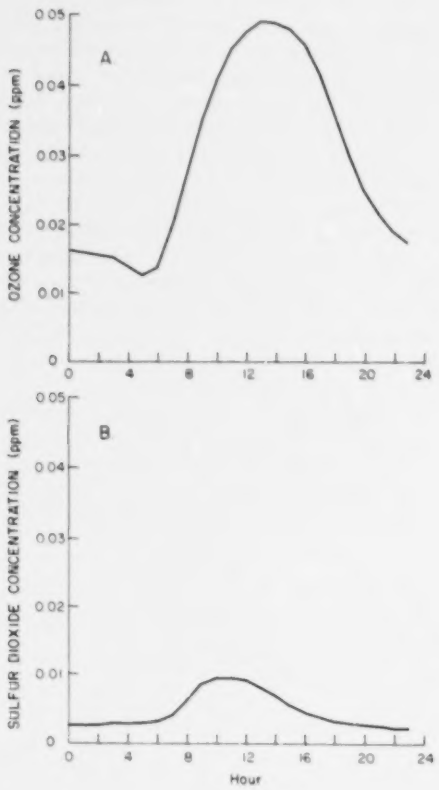

Fig. 1. Average diurnal concentration patterns for (A) ozone and (B) sulfur dioxide over all five monitoring sites for April–October.

were few occurrences of SO_2 concentrations equal to or above 0.05 ppm over a 30-day period. The design of the SO_2 exposure profile focused on the intensity of the hourly concentration, duration and co-occurrence with O_3.

To develop a mixed pollutant profile we had to determine the number of hours SO_2 occurred with O_3 (co-occurrence) and without O_3. The calculation was based on the presence of both pollutants at concentrations equal to or greater than 0.05 ppm during the same 24-h period. The hour-by-hour data indicated this condition existed for a total of 99 h for all four sites during the 7 months. This equals to an average of 25 h per site for 7 months, or about 4 h per month when SO_2 and O_3 occur on the same day with both concentrations exceeding 0.05 ppm for at least 1 h. The air quality data from the four Florida sites indicated that there was an average of 10 h per month with SO_2 levels above 0.05 ppm (Table 5). Since the data analysis indicated an average of 4 h of SO_2 co-occurring with O_3, one could anticipate approximately 6 h of SO_2 (at concentrations equal to or greater than 0.05 ppm) without O_3 concentrations being equal to or greater than 0.05 ppm during a 30-day period. The type of co-occurrence, i.e. simultaneous or sequential, was not determined in this calculation.

The probability of sequential co-occurrence was calculated from the hourly monitoring data for the April–October period as the percent of the total days that the two pollutants occurred on the same day above a 0.05 ppm minimum concentration for each site and averaging for all sites. The probability of a sequential co-occurrence was about 5.5% of the time, or about 2 days during a 30-day period. Similarly, the probability of simultaneous occurrence was determined by averaging the percent of total days over all sites when O_3 and SO_2 occurred above the minimum concentration (0.05 ppm) in the same hour and the same day. This was 1.4% of the time, or approximately one event every 60 days. Using these probabilities, the base O_3/SO_2 profile was designed with two sequential occurrences in 30 days and no simultaneous events.

The mean duration of the SO_2 peak (≥ 0.05 ppm) on co-occurring O_3/SO_2 days over the 7-month period and over all sites was calculated from the hourly data to be 2.3 ± 1.9 h per day. SO_2 levels equal to or greater than 0.05 ppm averaged 10 h per 30 days (Table 5). The average peak duration for SO_2 was assumed to be similar with and without O_3 levels above the minimum

concentration. Thus, the base profile was designed with 2 days of sequential co-occurrence and 2 days when SO_2 appeared without O_3 above 0.05 ppm.

The shape of the sequential co-occurrence for the base profile was determined by plotting hourly data from all sites over the 7-month period. On days when SO_2 and O_3 were both above the minimum concentration, the SO_2 concentration reached a maximum before the O_3 peak. Frequently, the SO_2 peak occurred as a shoulder to the rising O_3 concentration and this shape was incorporated into the base profile.

To identify the days on which SO_2 was present for the base profile required determination of whether high concentrations of hourly O_3 occurred on the same day as high SO_2 concentrations. This question was addressed by examining the hourly averaged O_3 data for those days when the SO_2 concentration exceeded 0.12 ppm for the four sites. As an example, the Pensacola site experienced 9 h of O_3 at 0.09 ppm or greater, yet there were no SO_2 peaks on those days. Similar patterns of no high SO_2 peaks during days of elevated O_3 were observed at the other sites. Thus, in designing the base profile, the highest hourly averaged SO_2 concentrations were not programmed for the same day as the higher O_3 peaks. Because SO_2 occurred at variable times in the hour-by-hour data from each site, the base profile was constructed with one sequential SO_2 occurrence in the morning and one in the afternoon.

The base O_3/SO_2 profile was constructed by hand. A 30-day, 24-h/day matrix was filled with concentration values to meet the average frequency of hourly occurrence within specified concentration ranges determined for the monitoring sites (Table 5). The placement of ozone peak days (maximum concentration equalled or exceeded 0.08 ppm) was based on the hourly data and by observing a pattern of several (2–4) clustered peak days followed by a variable number of non-peak days during each month. The hourly concentration values during each 24-h period were placed to approximate the gradual concentration rise and decline shown in the average diurnal plots (Fig. 1); the maximum levels occurred each day at 1300-1500 h. The placement of the maximum SO_2 concentration and duration of the episode was determined by the values in the base O_3 profile so that both the sequential co-occurrence characteristic was reproduced as well as the occurrence of SO_2 without O_3. The base exposure profile is shown in Fig. 2. The limiting of the profile to a 30-day regime is for convenience, and for an element of control in experimental design of exposure studies where the 30-day regimes will be repeated over a 5–7 month growing season.

Two additional sets of profiles were constructed from the base exposure profiles. One was created to assess the importance of concentration in eliciting a response in vegetation (altered concentration profiles) (Fig. 3). This profile was constructed by multiplying all hourly O_3 concentrations equal to or greater than 0.07 ppm in the base profile by 1.2 and 1.4. All SO_2 concentrations equal to or greater than 0.05 ppm were multiplied by two and four. The 0.07 and 0.05 ppm levels were selected as the minimum value to alter because they represent the beginning of the concentration ranges that occur relatively infrequently (Table 5). The multipliers were arbitrary, but selected to not increase concentrations to unreasonable or unexpected hourly values. Unlike the base profile, these altered profiles were not meant to mimic a specific ambient air quality but rather to provide a range of exposure conditions for fumigation studies.

A second set of exposures was developed to test the importance of increased episodes in eliciting a response in vegetation (increased frequency profiles) (Fig. 4). Days in which the maximum O_3 concentration equalled or exceeded 0.08 ppm were repeated one or

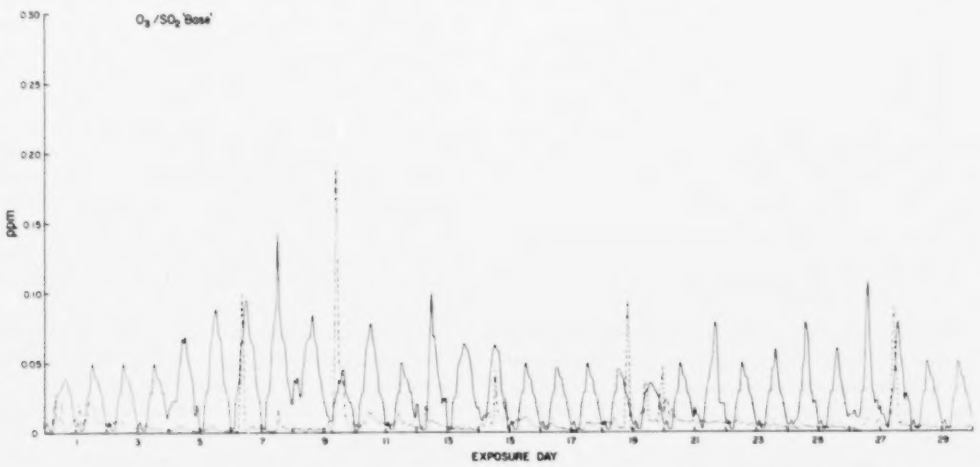

Fig. 2. The 30-day base profile for ozone and sulfur dioxide. ( ) Ozone; (– – – –) sulfur dioxide.

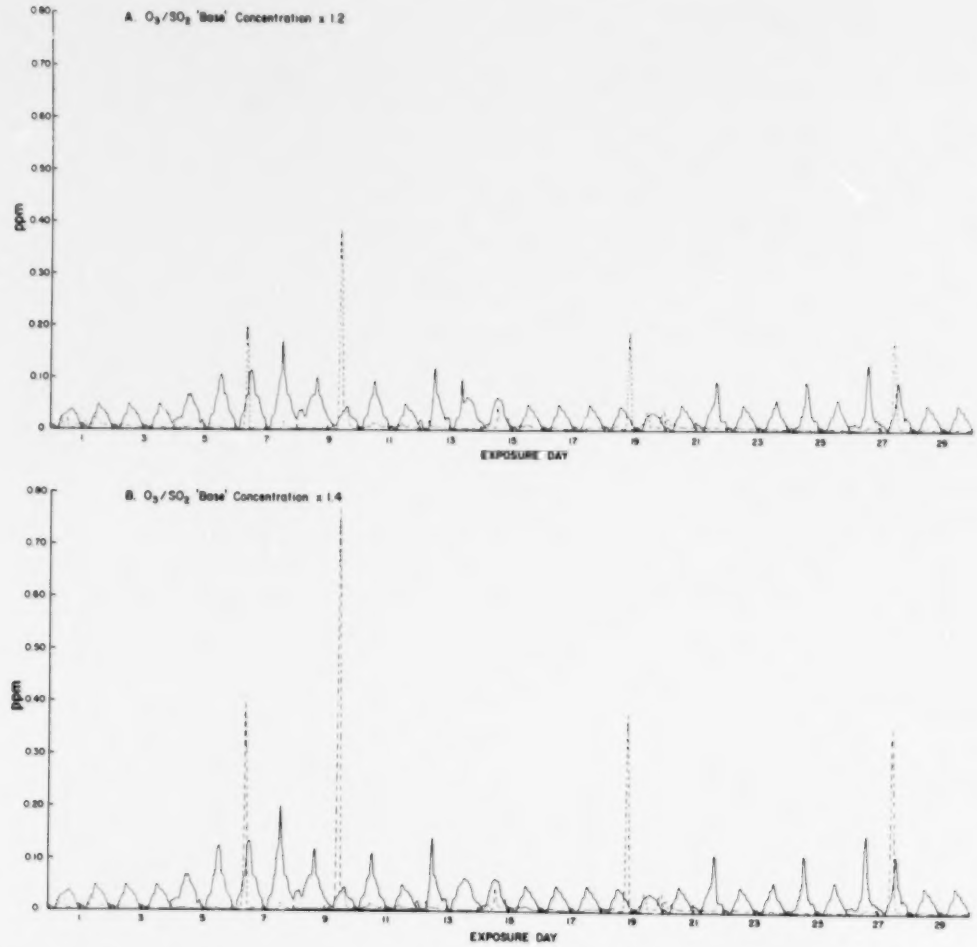

Fig. 3. The 30-day altered concentration profiles. ( ) Ozone; (– – – –) sulfur dioxide. Hourly ozone concentrations equal to or greater than 0.07 ppm multiplied by 1.2 and 1.4. Hourly sulfur dioxide concentrations equal to or greater than 0.05 ppm multiplied by 2 and 4.

two more times in the 30-day profile by replacing the values for those days when the concentration did not exceed 0.05 ppm. The increased episode SO_2 profiles were constructed similarly, but the peak day defined as one when an hourly SO_2 concentration equal to or greater that 0.05 ppm occurred.

SUMMARY

The base profile was constructed with hourly O_3 concentration values approximating the average frequency of occurrences within specified ranges for all sites. Although some adjustments were necessary to reproduce realistic fluctuations, the O_3 frequency of occurrence was within one–two standard deviations from the mean (Table 5). This technique permits development of an experimental profile with an O_3 percentile distribution similar to the average of the monitoring sites used for the analysis, and thus typical of ambient O_3 distributions. The duration of O_3 episodes and the time between episodes for the base profile were within one standard deviation of the mean for the five sites except for the 0.10 ppm minimum concentration (Tables 6 and 7). The profiles for altered concentration and increased episodes show percentile distribution patterns that are skewed toward the higher concentrations (Table 4), but conditions were within the range seen in the monitoring data at the sites.

The percentile distribution of SO_2 varies considerably over the five monitoring sites (Table 4) and over the region (Table 3), but hourly concentration at any given site depends upon the emission strength, meteorological conditions, and the distance between the source and monitoring site. Data showed occa-

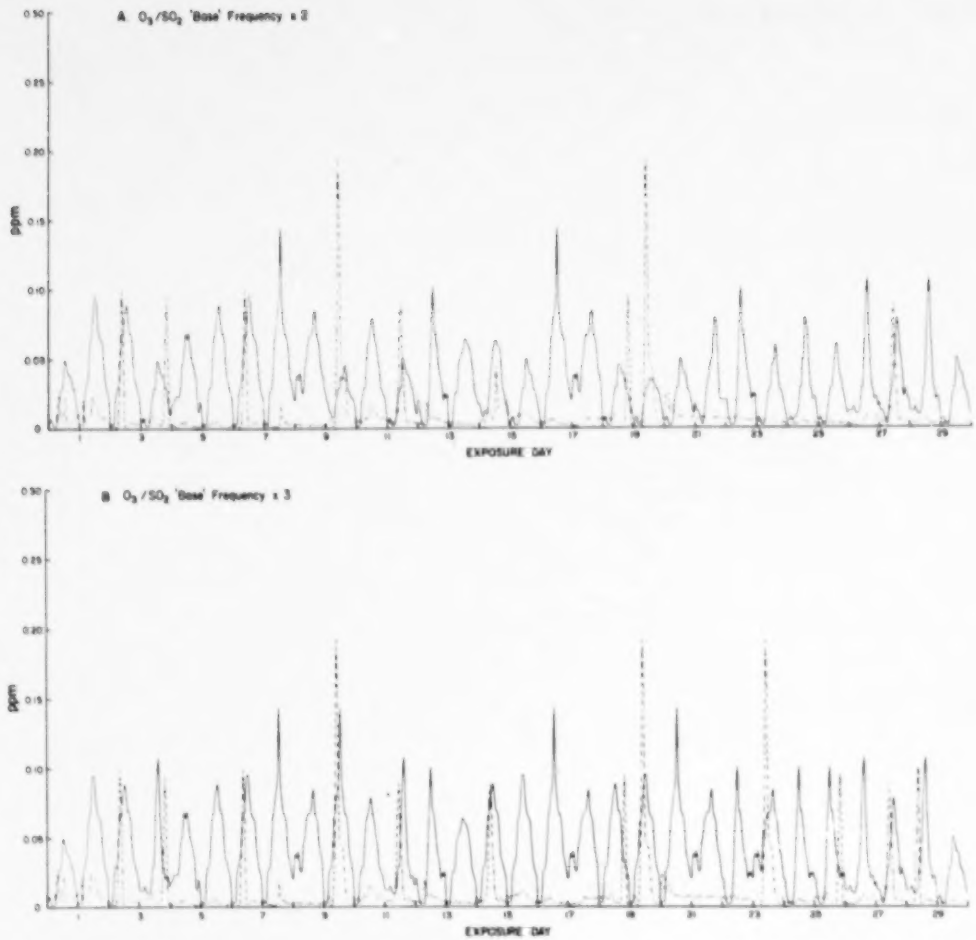

Fig. 4. The 30-day increased frequency profiles. ( ) Ozone; (– – – –) sulfur dioxide. The days in which the hourly ozone concentration equalled or exceeded 0.08 ppm were repeated 1 (A) or 2 (B) more times on those days when the maximum concentration did not exceed 0.05 ppm. The SO_2 profiles were constructed similarly except the concentration had to exceed 0.05 ppm.

sional point source impacts, but most of the hourly averaged SO_2 concentrations were equal to or less than typical minimum instrument detection levels. The SO_2 concentrations in the base profile matched fairly well with the four Florida sites used to design the concentration regime; the concentrations were equal to and above 0.05 ppm within one standard deviation of the mean. The maximum SO_2 hourly mean concentrations did not agree, but the elevated concentrations vary considerably from site to site.

Consistent with the findings of Lefohn and Tingey (1984), the analyses of data from the Florida sites showed that the number of O_3/SO_2 co-occurrences over a growing season was small. The type of co-occurrence appeared to be predominantly sequential; simultaneous co-occurrences were rare. These characteristics of co-occurrence were reproduced in the base profile.

In summary, an experimental 30-day O_3/SO_2 base exposure profile was constructed from hour-by-hour monitoring data which had been characterized and averaged over a number of sites. The base profile as well as the altered profiles provide an element of realism to fumigation studies and a design element needed to relate plant growth/yield or physiological response in laboratory experiments to ambient air quality.

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16. ABSTRACT
A design for constructing experimental mixed-pollutant exposure profiles that reflect regional O^3 and SO_2 ambient air quality is described. The profiles were developed using hour-by-hour O_3 and SO_2 concentration data from monitoring sites in the southeastern United States where slash pine is indigenous. Only sites designated rural or remote, with co-monitored O_3 and SO_2, and at least 75% of the hourly values reported for the period April-October, were used. Each site was characterized by concentration frequency of occurrence and duration of concentration values, length of time between episodes, and frequency of co-occurrence. A base profile, a 30-day hour-by-hour concentration regime, was constructed using averaged air quality characteristics from the selected sites. Using the base profile, additional regimes were constructed by increasing the concentration of all hourly values above a designated minimum, or by increasing the frequency of occurrence of selected hourly concentrations.

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